# The SCaN Testbed on the International Space Station (ISS)

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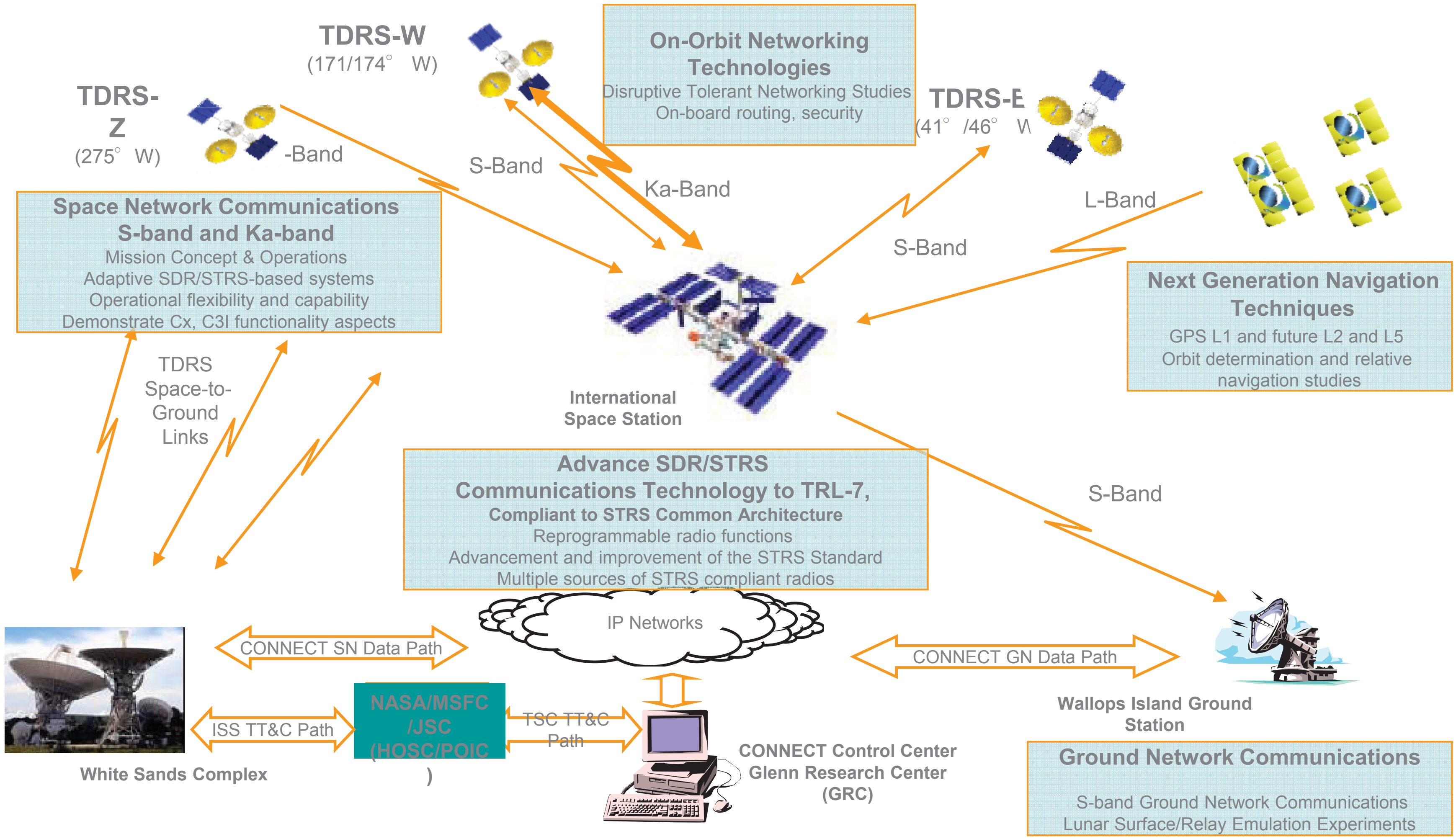
**WFK: Practical Design Approaches and Issues in Software Defined Radios**

# Outline

- What is the CoNNeCT Project and the SCaN Testbed?
  - What's different about "Space" and "flight qualified" and why CoNNeCT helps
- What is available on the testbed
  - Software Defined Radios (JPL, GD, Harris)
  - Antennas & visibility
  - Data Paths
- NASA's Standard Software Radio Architecture
  - Software Architecture
  - A closer look at the JPL radio
- Experiment Process
  - How your experiment works it's way through the process
- Proposal Process
  - How to get access to the testbed and fly your experiment

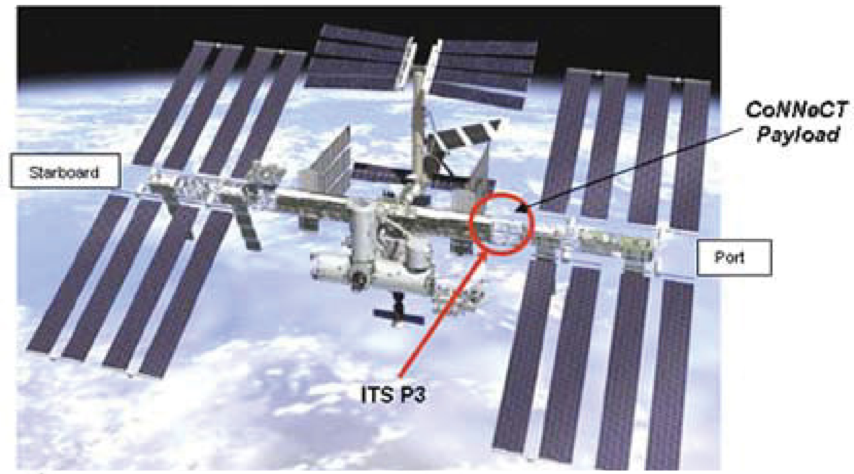
# CoNNeCT

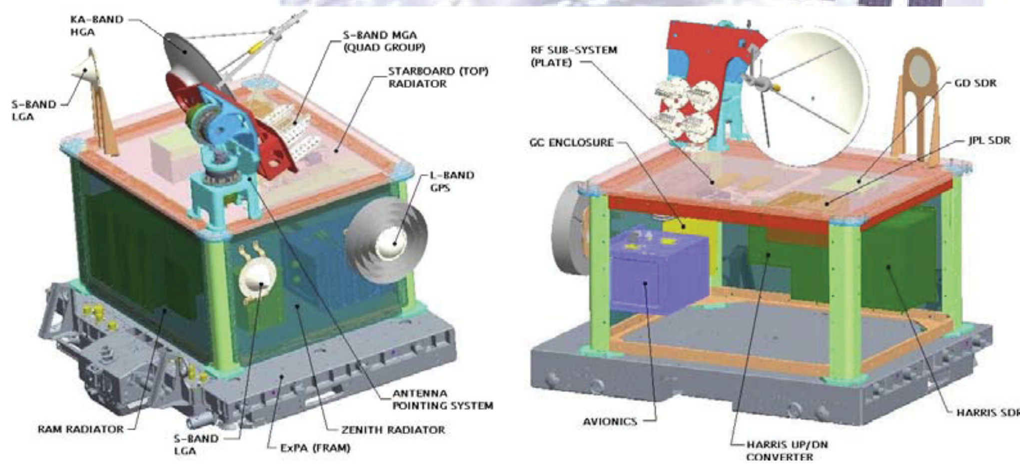
## Communications Navigation and Networking ReConfigurable Testbed



# SCaN Testbed on ISS

- NASA Space Operations Mission Directorate (SOMD), Space Communications and Navigation (SCaN) Program
- 3 Software Defined Radios (SDRs), antennas, and a flight computer on International Space Station
- Launching in January 2012, available for experimental operations starting summer 2012
- Minimum life of 2 years, through 2014




More info: http://spaceflightsystems.grc.nasa.gov/SpaceOps/CoNNeCT/

# What's "Flight Qualified"?

## And why do we care?

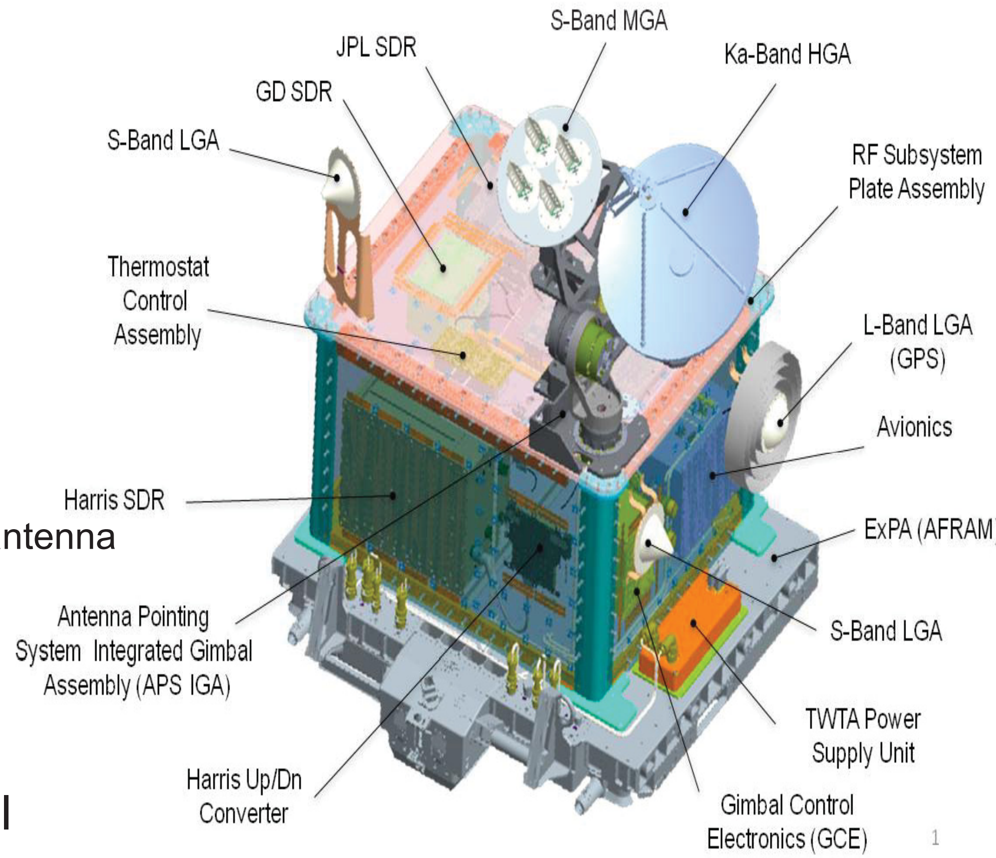
- Conservative design philosophy for design and parts selection
  - You can't bring it back to fix it
  - Use what has worked before, unless there's just no other way.
  - "Space Qualified" components preferred
    - Limited choices for packages (hermetic, ceramic)
    - Radiation test data available
    - Very long lead times (18-24 months)
- Conservative operating philosophy
  - No surprises! Everything rehearsed and tested on the ground
  - Don't "brick the box" with a software upgrade (it might be the only box)
  - Very skinny data pipe (bps to kbps) to the box for software upgrades, debug info, etc.
- Very long development and use cycles compared to commercial world
  - Mission proposal to launch = 5-6 years
  - Hardware selection >3 years before launch
  - Cruise phase to outer planet = 5-6 years
  - Operating phase: years and years
- Small acquisition quantities
  - 1 Engineering Model (EM), 1 Flight Model (FM)
  - Maybe 2 FMs and maybe a spare ("single string" is becoming the norm, EM as spare)

"Why don't we just do it like someone else has done it successfully before?"

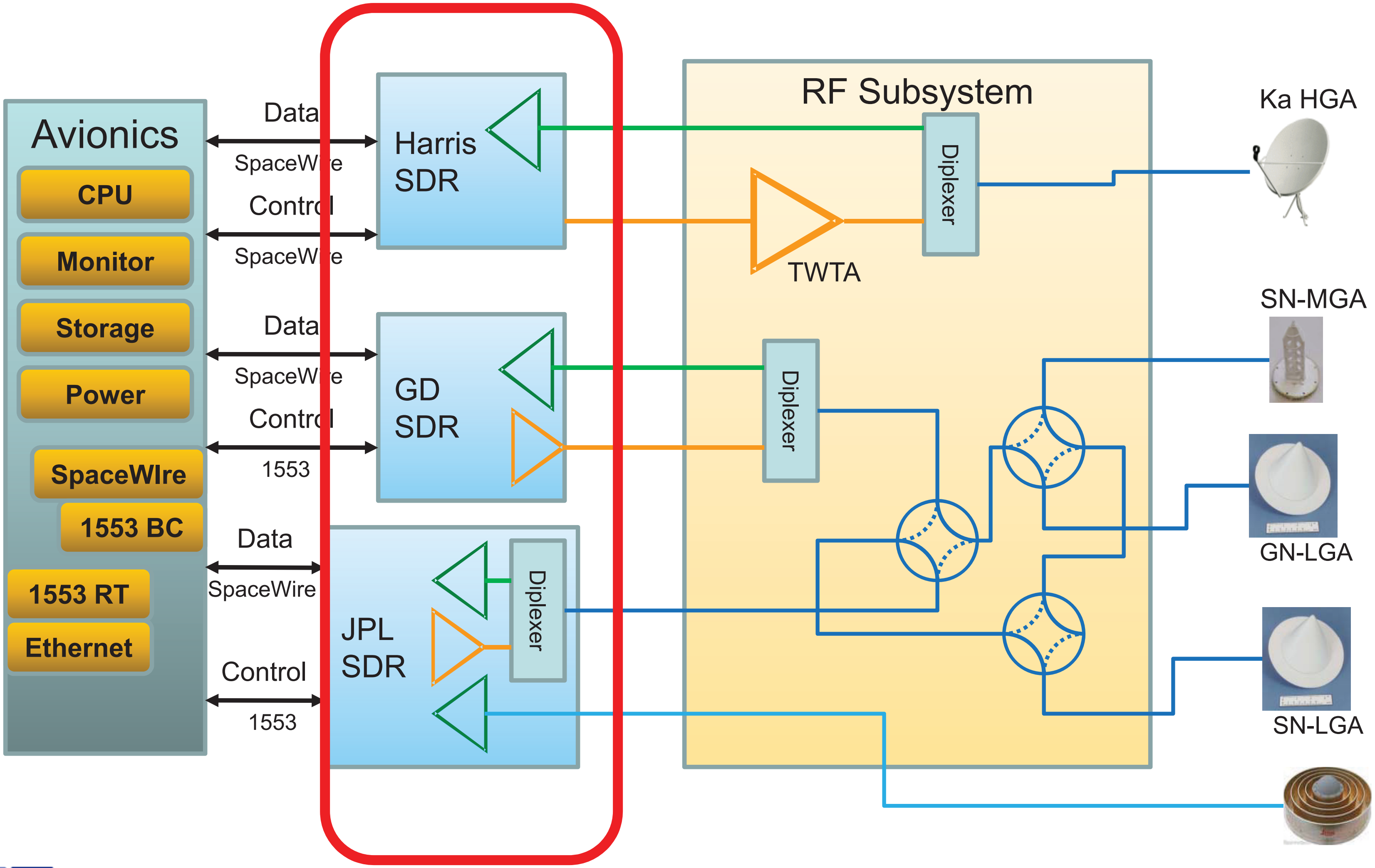
CoNNeCT provides a way to get "flight experience" for new designs and approaches, without risking a science mission.

# Flight System Overview

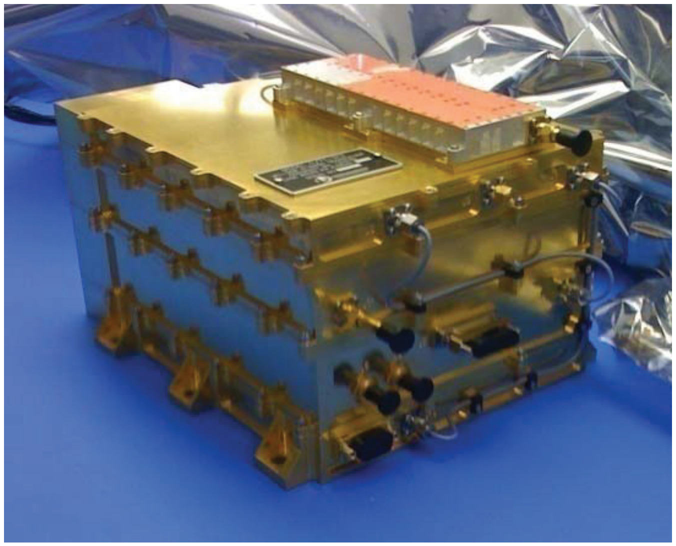
- Flight Computer/Avionics
  - Rad750 + Solid State Disk + interfaces
- Communication System
  - SDRs
    - 2 S-band SDRs (1 with GPS)
    - 1 Ka-band SDR
  - RF
    - Ka-band TWTA
    - S-band switch network
  - Antennas
    - 2 - low gain S-band antennas
    - 1 - L-band GPS antenna
    - Medium gain S-band and Ka-band antenna on antenna pointing subsystem.
  - Antenna pointing system.
    - Two gimbals
    - Control electronics
- Flight enclosure provides for thermal control/radiator surface.



# SCaN Testbed - Radios



# The JPL Software Defined Radio



28.2 L x 20.6 W x15.5 H cm
6.6 kg
15 W Rx (typical)
+ 2 W (GPS)
+ 65W Tx S-band

STRS Operating Environment
- RTEMS OS – POSIX interface
- In memory file system
- All open source

Digital Processing
- 66 MHz SPARC V8
- 128 MByte SDRAM + 512 MByte Flash
- 2x Xilinx Virtex II 3Mgate FPGAs
- SDRAM and Flash on each FPGA

Control and Data Interfaces
- MIL-STD-1553B
- 2 SpaceWire Links (ECSS-E-50-12C)

Full Duplex S-band RF module
- Tx: 2.2-2.3 GHz, 5-10W output
  2 x 10bit, 50 MSPS DAC (I/Q)
- Rx: 2.025-2.12 GHz, 11 MHz BW, 2.5dB NF
  12 bit, 50 MSPS ADC

GPS Receive Sampler
- L1,L2,and L5

# General Dynamics StarLight™ SDR

STRS Operating Environment
- STRS 1.02 Compliant
- File system in SDRAM, configurable size
- VxWorks OS

Coldfire microprocessor (60 MIPS)
- 128 Mbyte Maxwell SDRAM
- 4 Mbyte Maxwell EEPROM
- 1 Mbyte BAE CRAM (Chalcedonide RAM)

Reprogrammable Devices
- Xilinx QPRO 2M gate FPGA
- Transparent scrubbing/correction of Xilinx configuration
- Error detection and correction for RAM

Control & Data Interface
- Dual redundant MIL-STD-1553B
- ECSS-E50-12A Spacewire

Full TDRSS S-band RF

Tx:
- 8 watt S-band Power Amplifier
- Phase noise < 2.0° rms, 10 Hz to 3 MHz
- Two 10-bit, 76 MHz D/A converters

Rx:
- 6 MHz bandwidth
- Noise Figure < 2.5 dB
- 14-bit, 76 MHz A/D converter

http://www.gd-ais.com/documents/AMT%20DS5-10-51.pdf

# Harris Corporation SDR

STRS Operating environment
- VxWorks
- based on Harris previous work SCA/JTRS/dmTK

Two boxes
- Ka-band up/down converter
- SDR Chassis
- <22kg, <125W

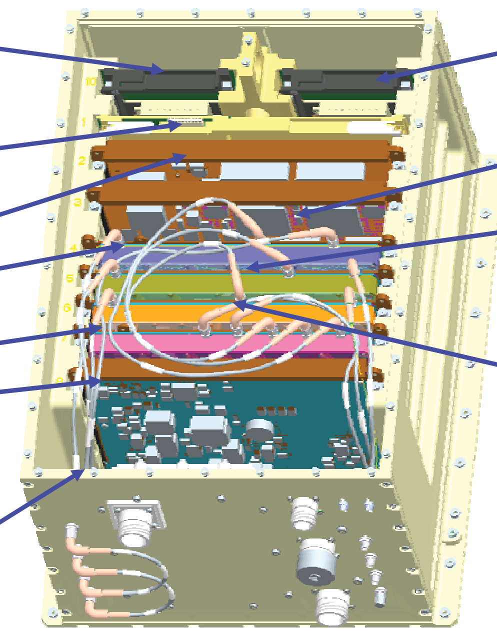
AiTech PowerPC
- 1000 MIPS

Flexible V4 Space Programmable Modem
- Controller ASIC
- 4 Xilinx XQR4VSX55 Rad Tolerant FPGAs
- SM320C6701 DSP
- 256 Mbytes EDAC protected SDRAM

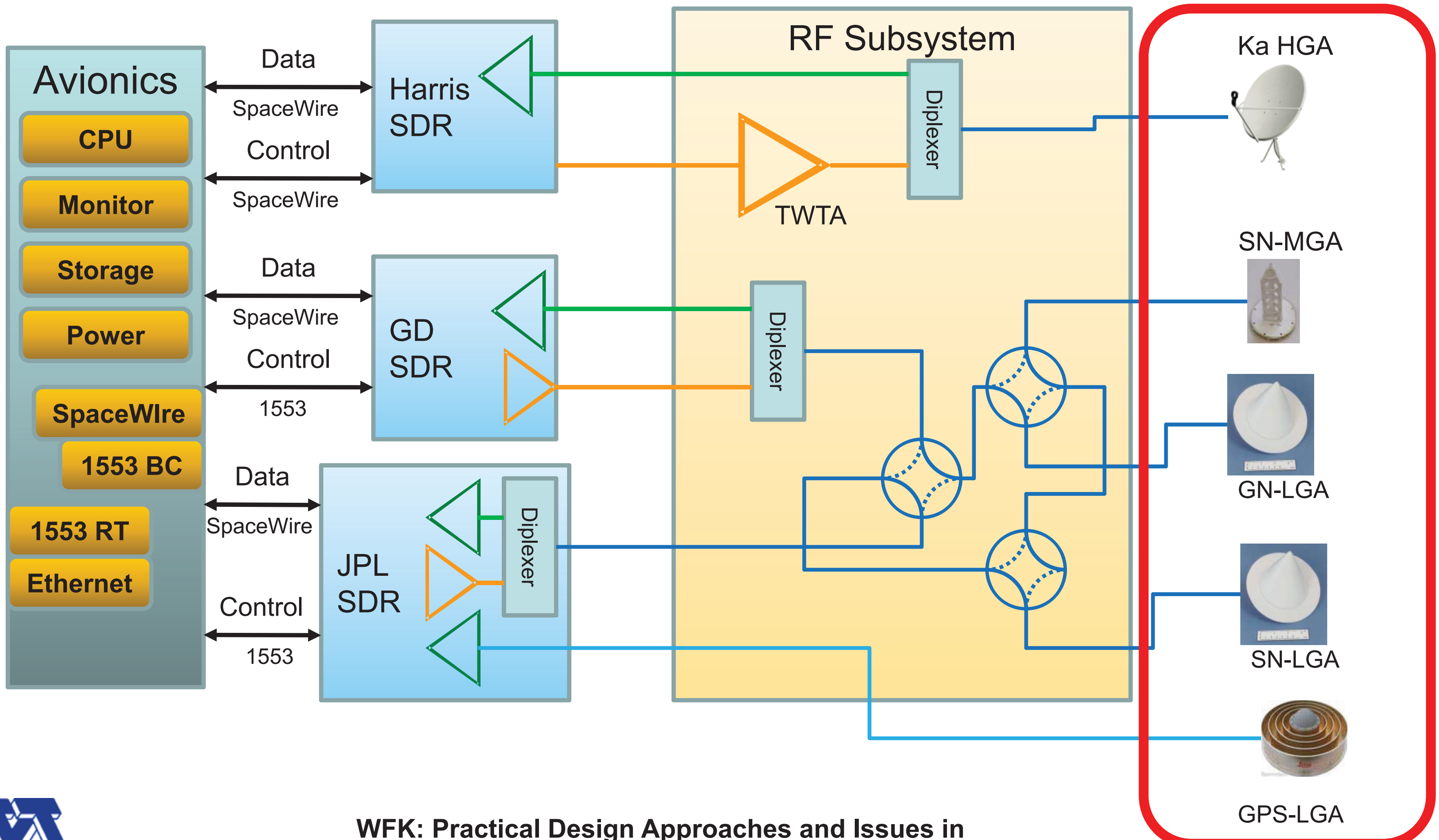
Control & Data Interfaces
- 2x SpaceWire
- Control interface uses RMAP

Tx: 25.650 GHz
- 0dBm (TWTA in RF subsystem)
- 2x 300 MHz DAC

Rx: 22.680 Ghz
- 100 MHz BW
- ADC 300 MHz



# SCaN Testbed - Antennas

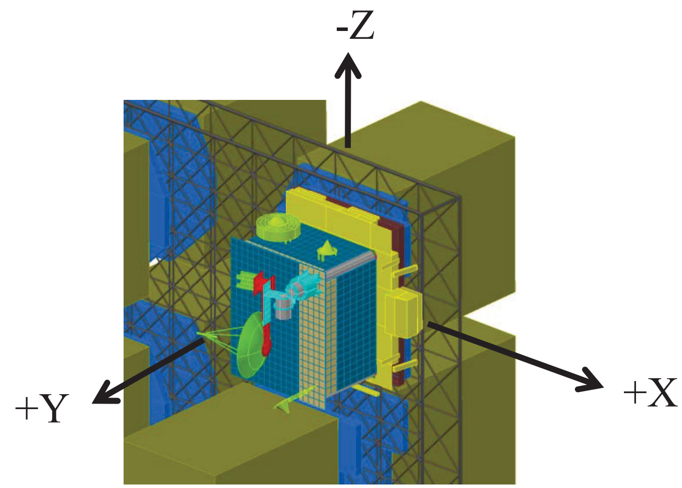


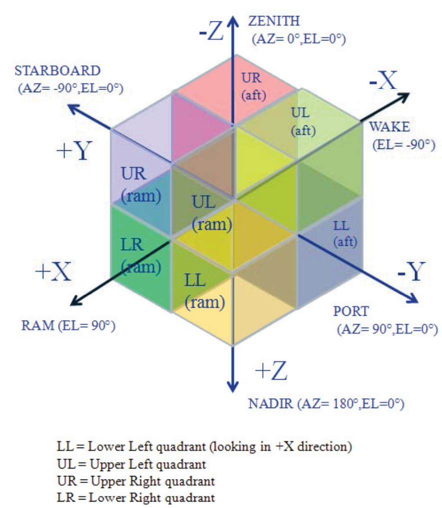

WFK: Practical Design Approaches and Issues in Software Defined Radios

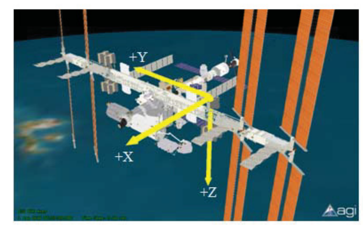
# Antennas for all bands and uses

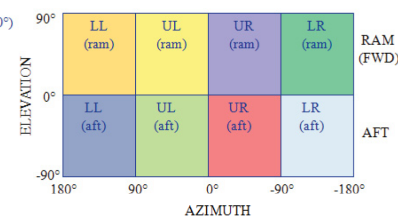
- L-band GPS
  - Low gain facing zenith
- 3 S-band antennas
  - Any antenna to either radio
  - Low gain facing Ram (GN-LGA)
  - Low gain facing Zenith (SN-LGA)
  - Medium gain (13dBi) on gimbal (SN-MGA)
- Ka-band
  - High Gain (40dBi) on gimbal (Ka-HGA)
- More can be found here:

  *GRC-CONN-PLAN-0103 Link Book*



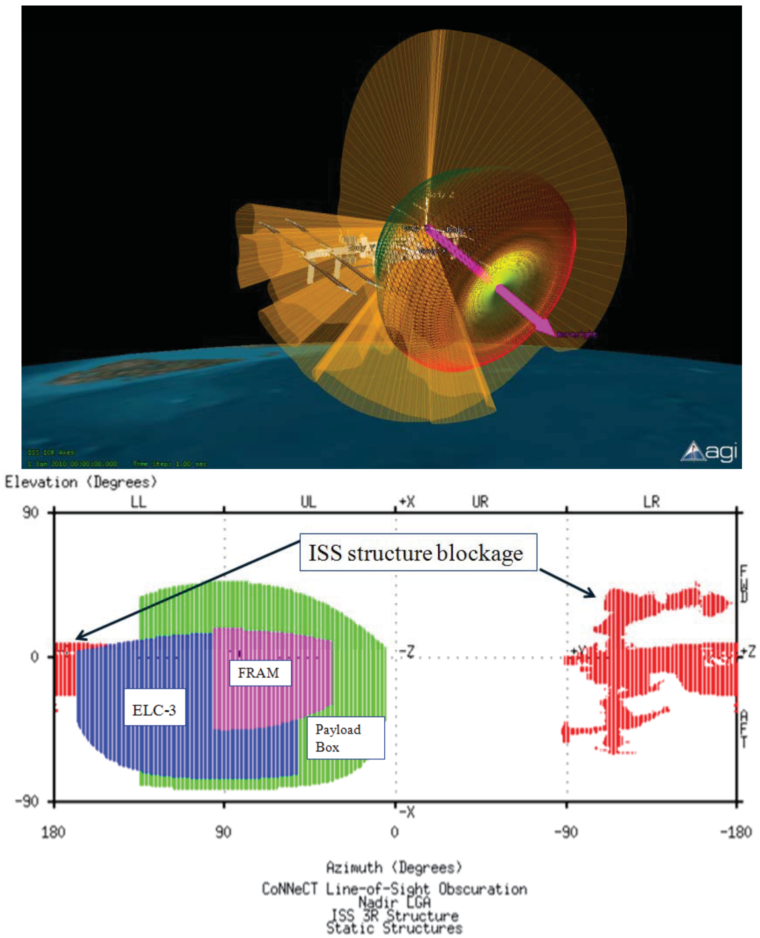



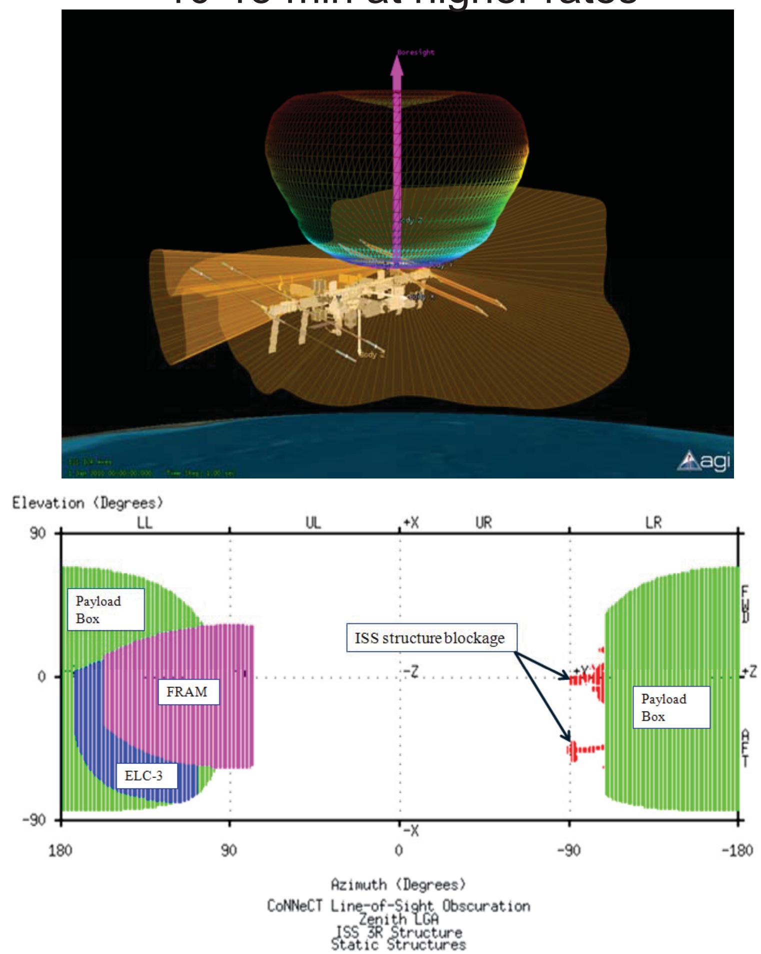



# Visibility: S-band LGAs

GN-LGA - to ground
(longest pass is 3.5 minutes)

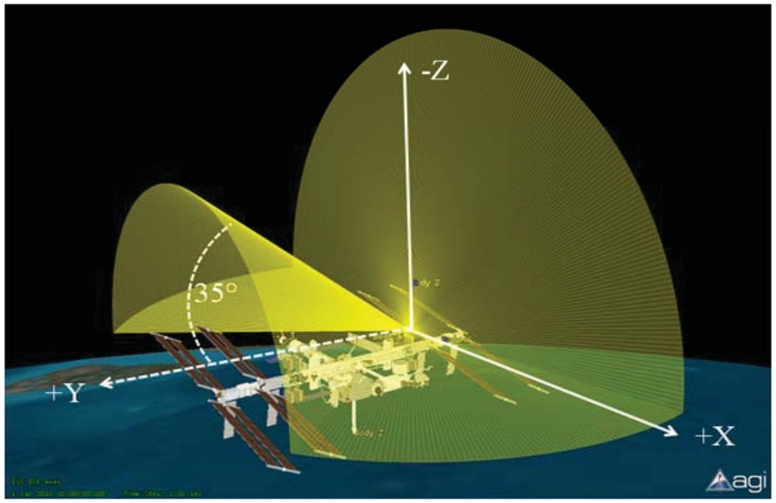


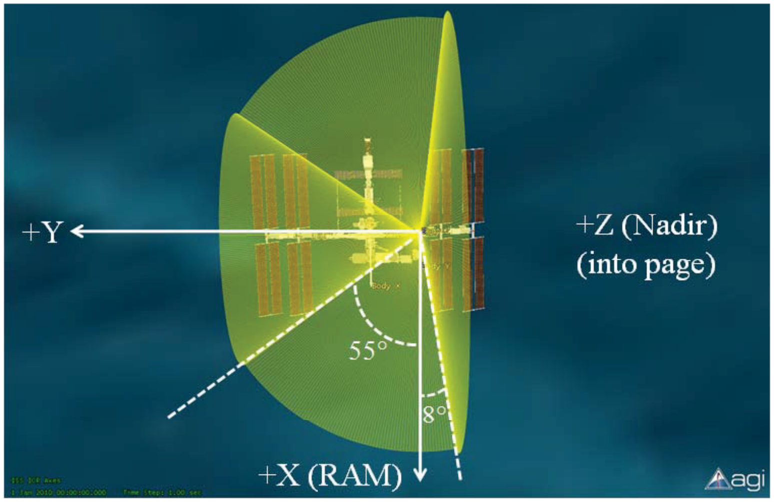

SN-LGA – to TDRS
Up to 40 minute pass at low rate,
10-15 min at higher rates



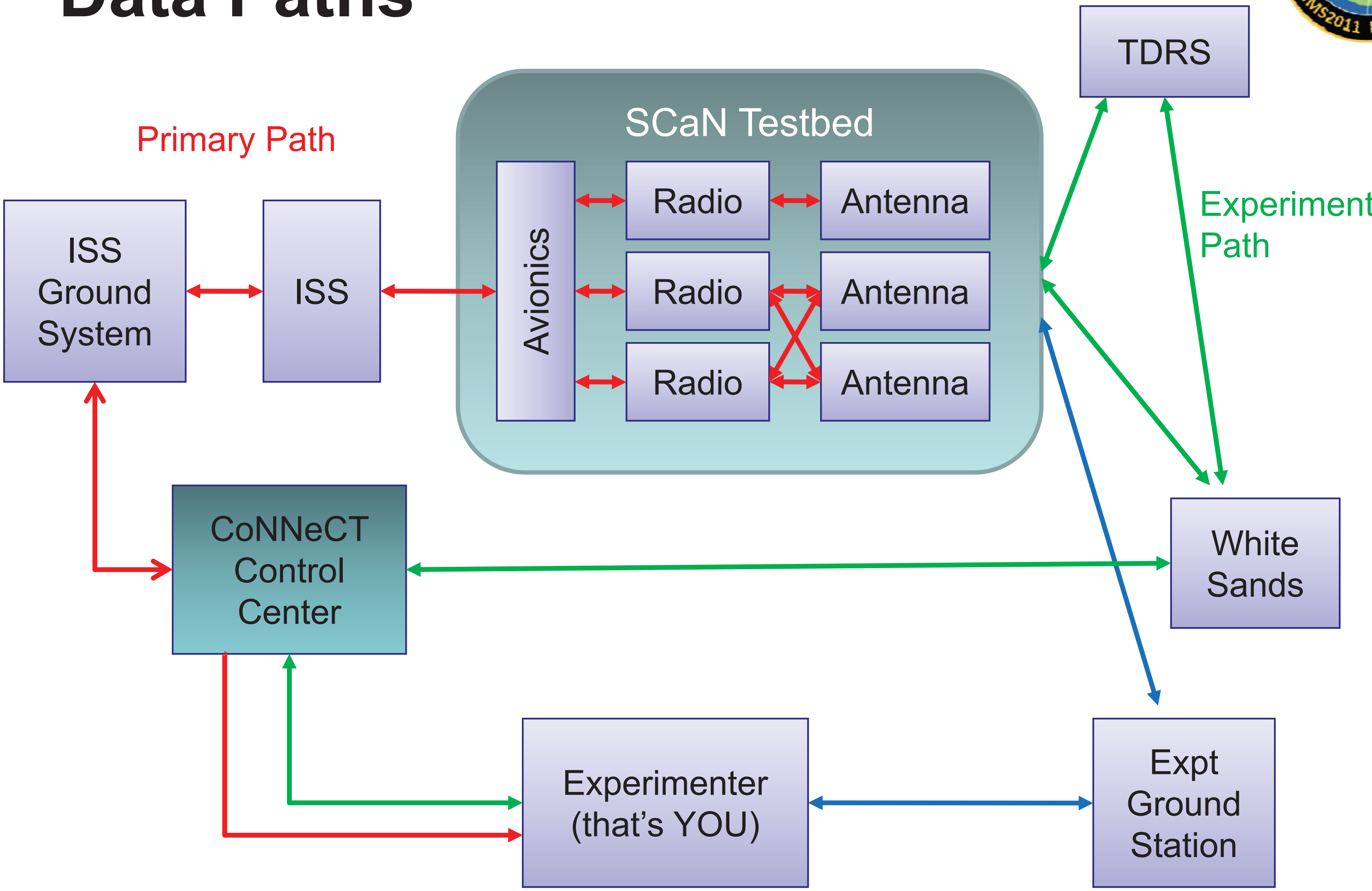
# Gimbaled antennas

- Generally faces “up” to track TDRS
  - Track profile under experimenter control
  - Some restrictions for safety
- 13dBi S-band
  - HPBW 36°
  - >200 kbps 40 min pass
- 40dBi Ka-band
  - HPBW 1.6°
  - 100Mbps return
    - (from testbed to ground)
  - 10Mbps forward
    - (to testbed from ground)
  - Data rates will be limited by EIRP and pointing accuracy



# Data Paths



SCaN Testbed
Primary Path
ISS Ground System
ISS
Avionics
Radio
Radio
Radio
Antenna
Antenna
Antenna
TDRS
Experiment Path
White Sands
CoNNeCT Control Center
Experimenter (that's YOU)
Expt Ground Station

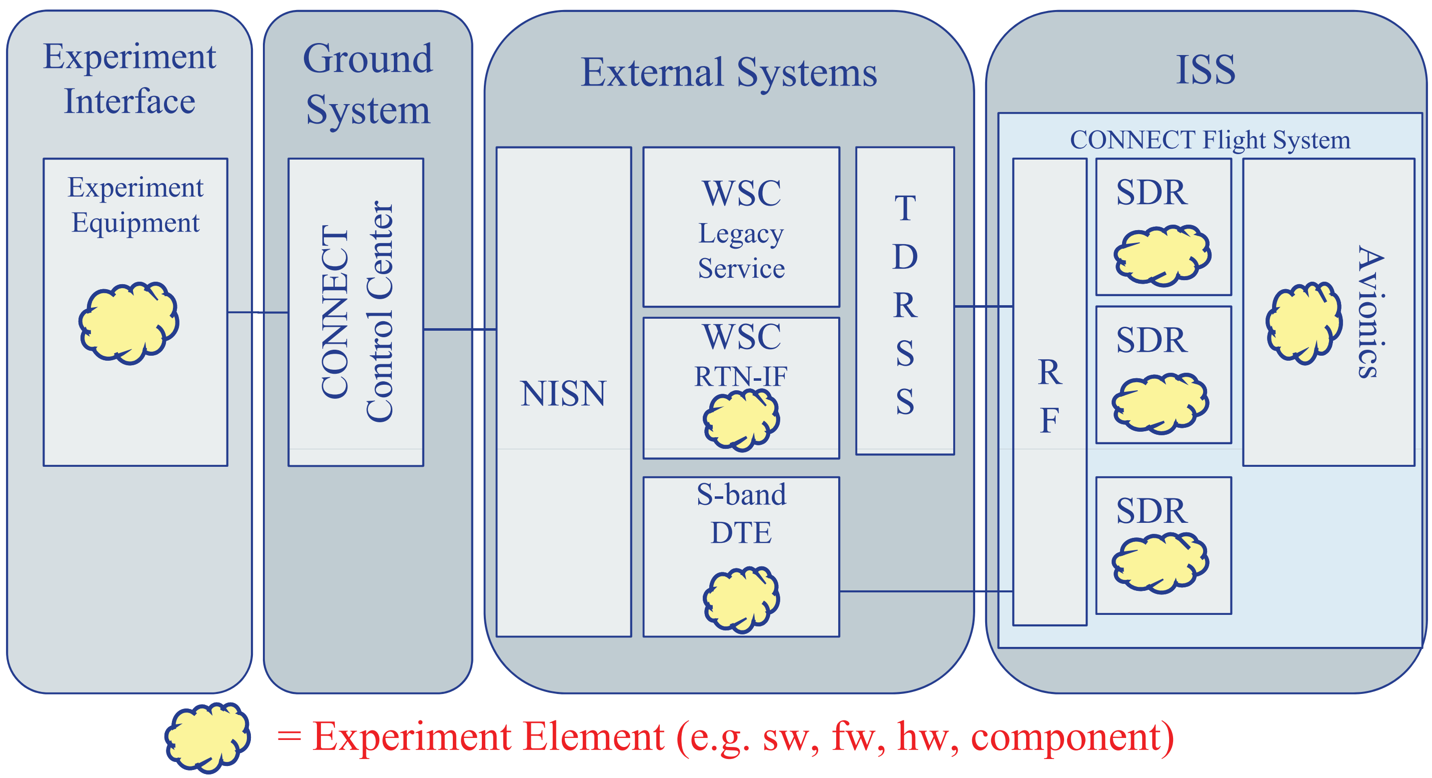
# Data Paths

- Primary Path: Through 1553 and Ethernet to ISS then to ground
  - Commands to SCaN Testbed
    - 1 every 100 ms, roughly 100 bytes/cmd
  - Low Rate Telemetry (LRT) from SCaN testbed
    - 380-12,000 Bytes/sec
    - 2 packets/sec nominal rate
  - File Transfer through 1553 and PLMDM
    - Both directions 5kByte/sec
  - Ethernet unidirectional from SCaN Testbed
    - 1484 byte packets at 10Hz = 15 kByte/sec

- Experimental Path: Through one of the radios
  - Various rates available from 1kbps to 100Mbps
  - Use one of existing waveforms or experimenter can bring their own.
- Eventually file transfers via Experimental link will be supported as infrastructure
- Variety of experimenter interfaces on ground
  - Clock/data
  - IP packets with raw bits
  - Frames

*GRC-CONN-DBK-0128 C*
*Command and Telemetry Databook*
*GRC-CONN-PLAN-0133*
*Mission Operations Plan*

# Experimenter Access Points

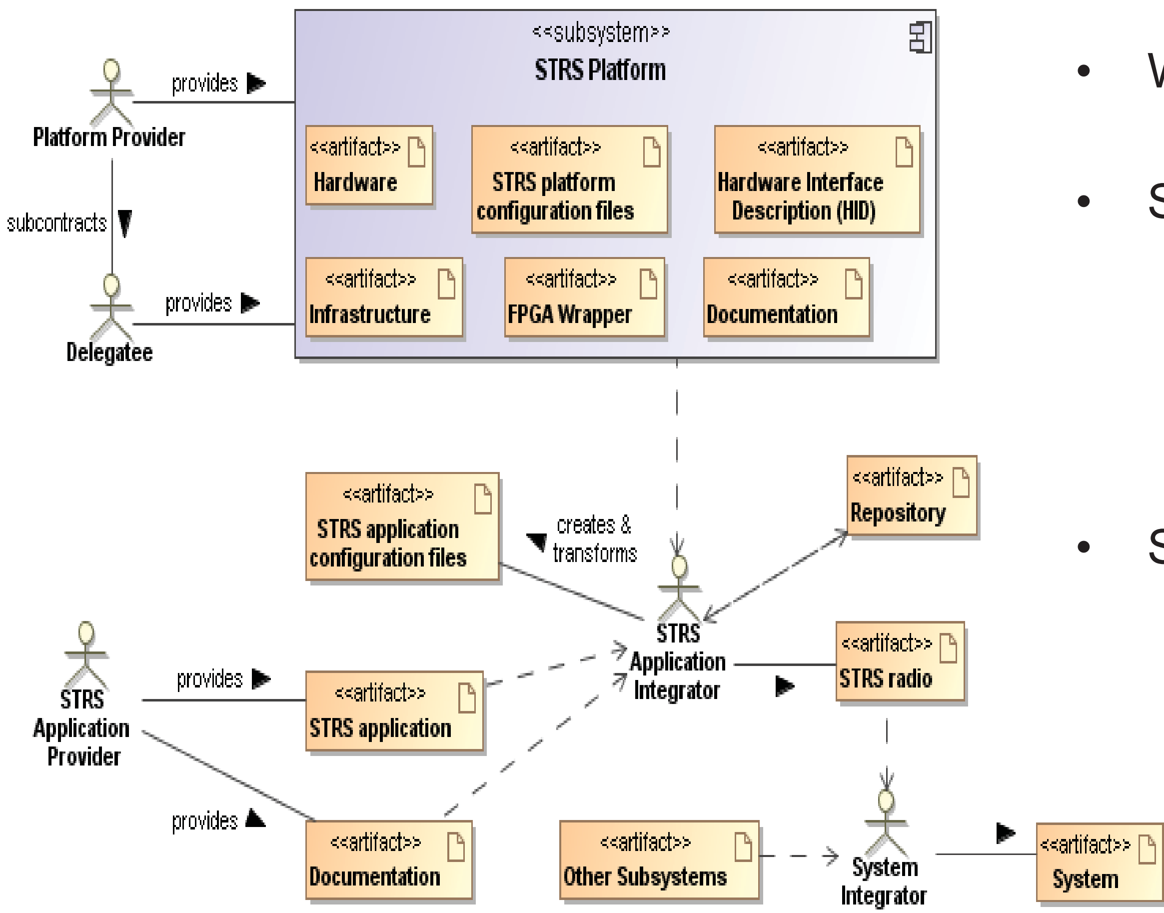



Experimenters have access to SDRs, avionics, various ground points

# A look inside the radios

- All the radios implement the Space Telecommunications Radio System (STRS) Architecture Standard
  - Evolvable Open Standard Architecture Specification: provides a common, consistent framework to develop, qualify, operate and maintain complex reconfigurable and reprogrammable radio systems.
  - Published interfaces
  - Standardized functions and abstractions
  - Applications are called “waveforms” (even if they don’t actually modulate or demodulate)
- A start towards the evolving nature of space flight radios
  - From end-to-end box from single supplier with single function…
  - To a platform with third party applications that define the function
- All the radios have a combination of general purpose processors (GPP) and Field Programmable Gate Arrays (FPGA) as well as RF, analog:digital conversion, control and data interfaces, etc.
  - About which more, later….
- Not really a radio with an embedded processor, but a network node that happens to have a RF capability
  - Type 500 from Ma Bell (in black, only) ▸ cell phone ▸ PDA ▸ mobile network node

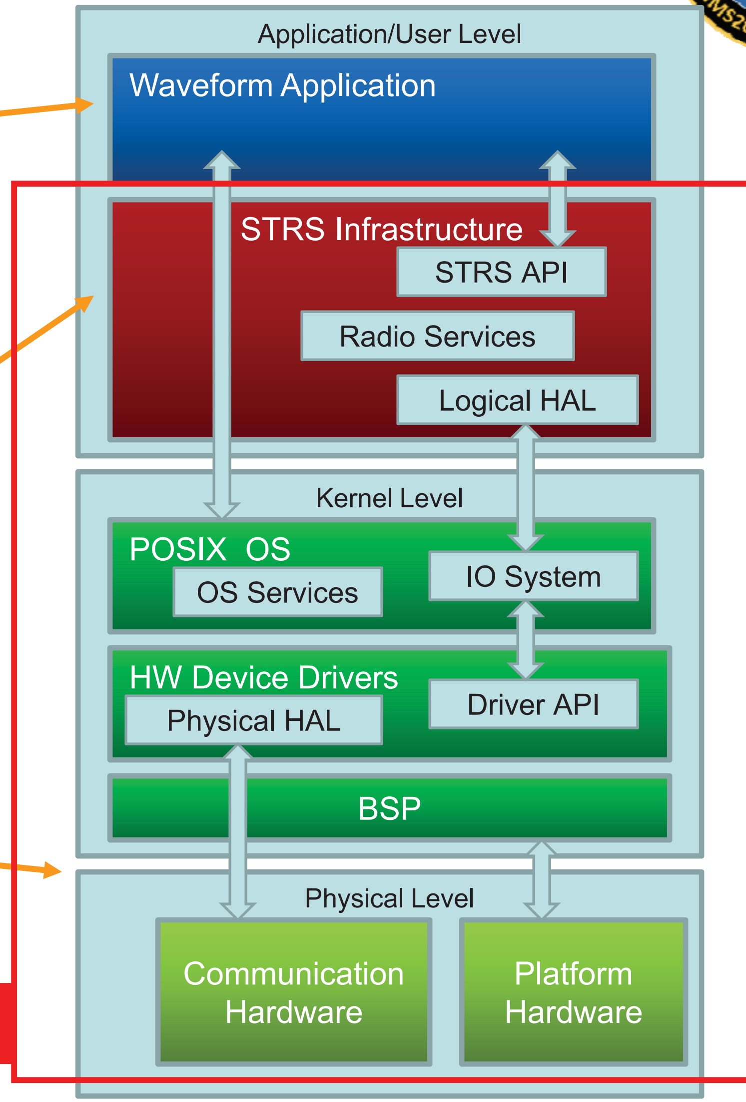
# SDR Developer Roles



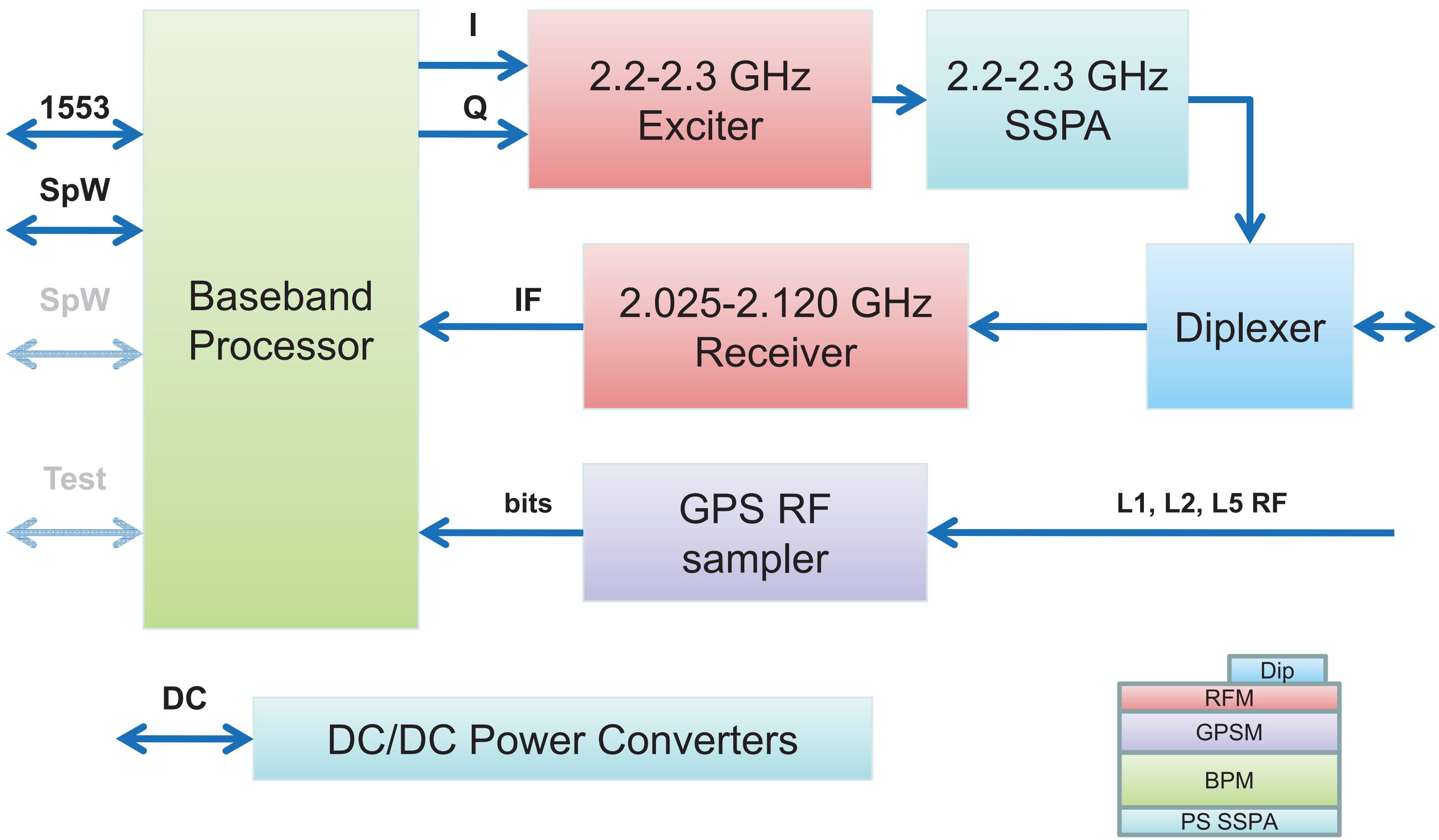

- Platform Supplier
  - Hardware
  - Operating Environment
- Waveform Developer
  - Waveform App
- SDR Integrator
  - Combines waveform applications with the platform.
  - non-SDR model, the integration is done at the radio manufacturer
- System Integrator
  - integrates the complete radio (hw/wf) with the rest of the spacecraft.

# Architecture

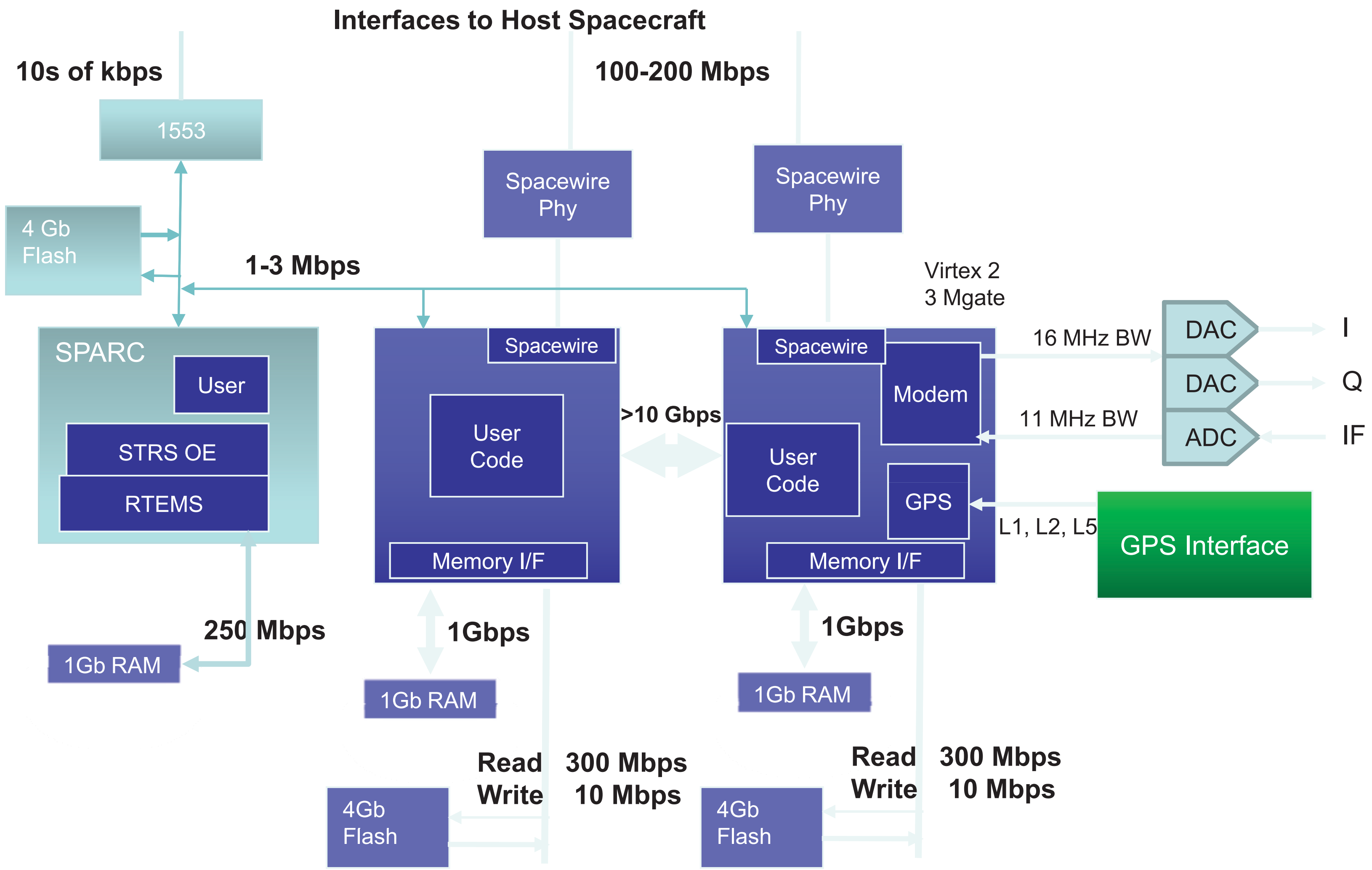
- Waveforms (applications)
  - Covers from EM wave to data interface
  - Not just the modulation
    - Framing
    - IP routing
- Operating Environment
  - OS (and its services)
  - Infrastructure
    - helpful stuff the OS doesn't provide
- Hardware platform
  - The metal, the electrons, the photons



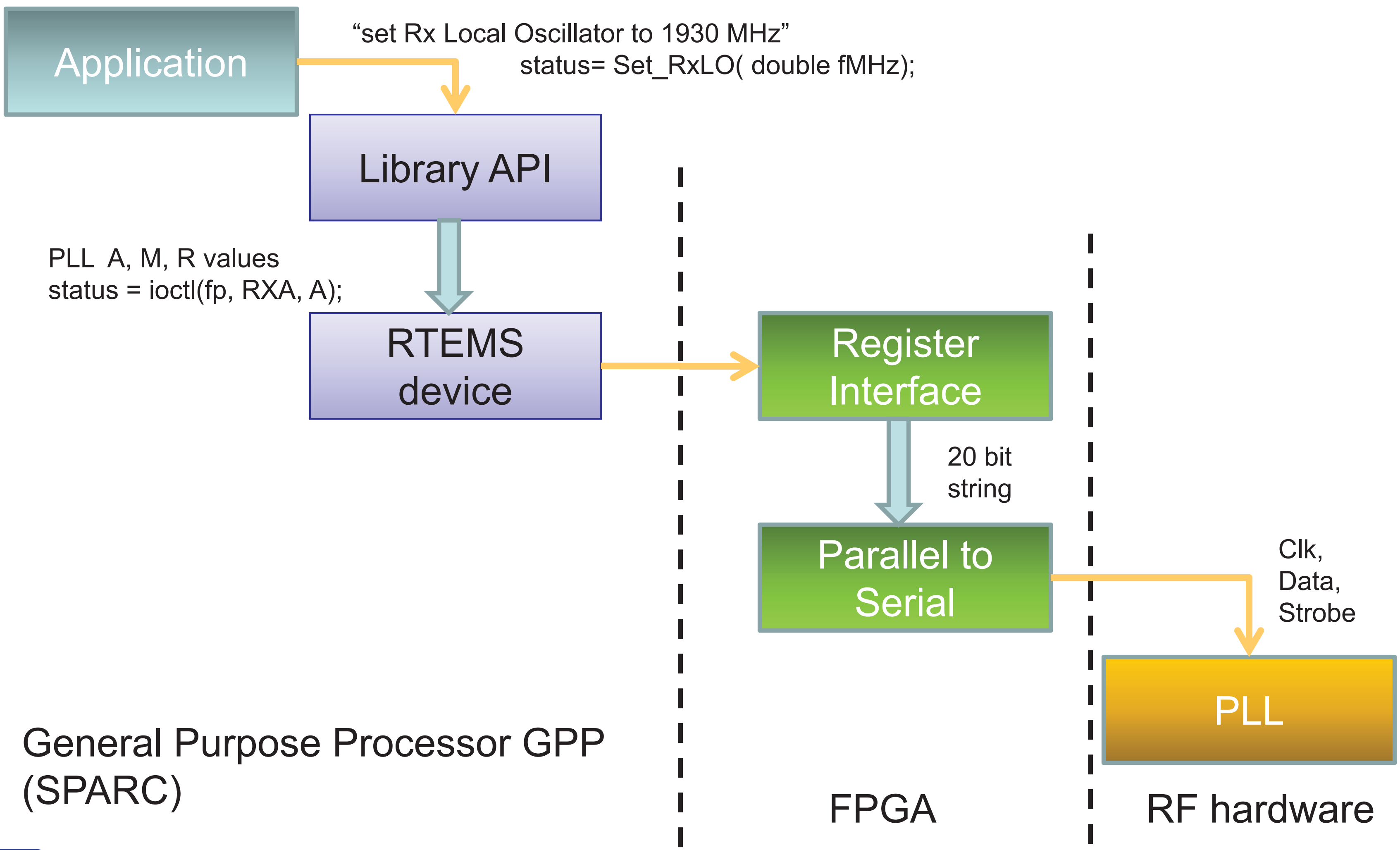
# JPL-SDR Hardware Overview



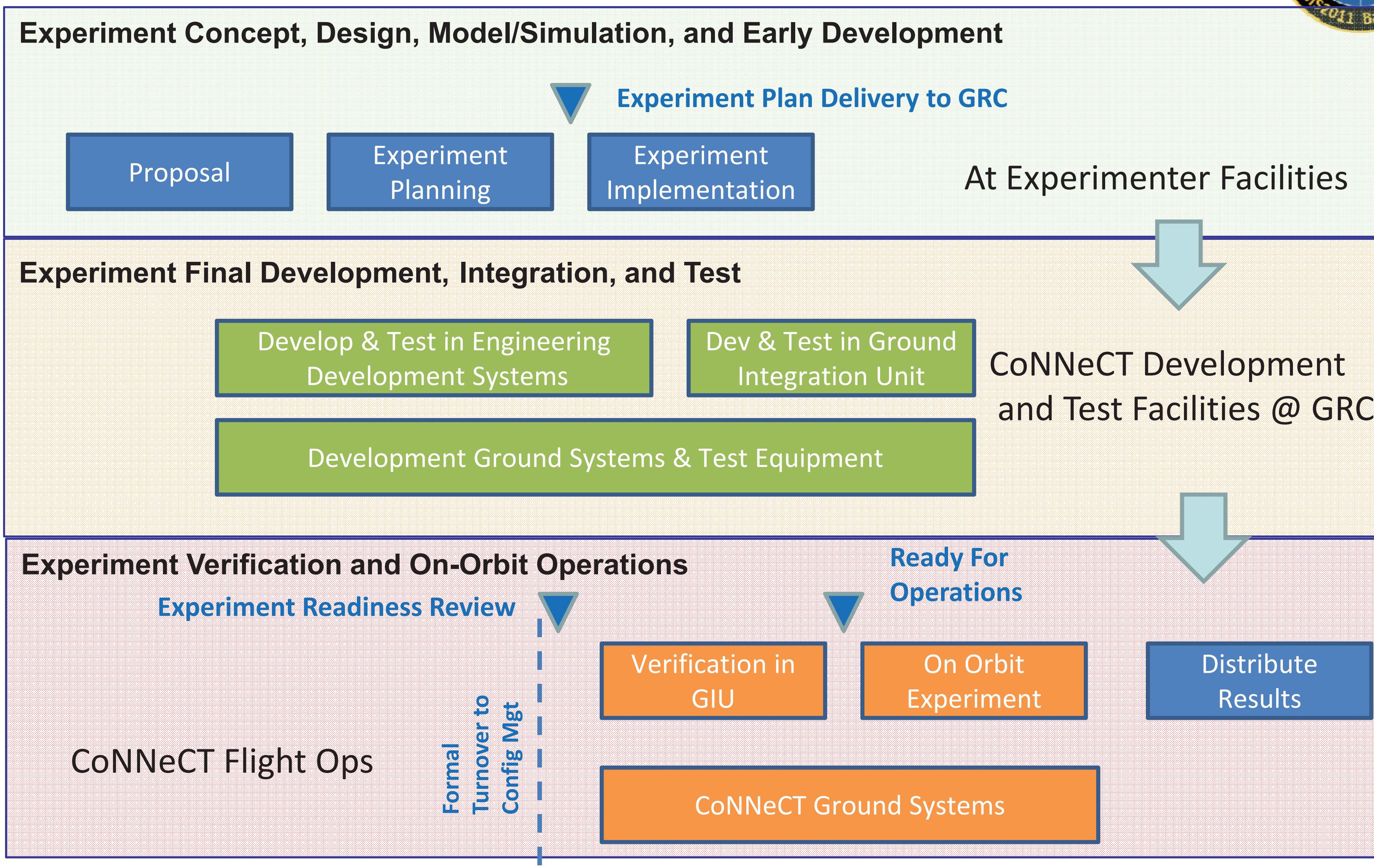
# Programmable Resources



# Abstractions of Hardware



# Typical Experiment Flow



# Experiment Activities and Milestones

- Experiment Plan delivered to CoNNeCT
  - Will include interface agreements, expected schedules, constraints, etc
  - Expect some comments and revisions from project
- Checkout and development in CoNNeCT or other facilities
  - Depends on level of complexity and interaction for your experiment (and whether you have local resources)
- Turnover to CoNNeCT - Experiment Readiness Review
  - Verification by project for safety, functions
  - Final check that everyone understands what's going to happen
- Ready to Schedule
  - Expect some months after turnover, will get faster with experience
- Run your Experiment
  - Detailed preparation starts 4 weeks before experiment
  - Scheduling, ops command sequence building, etc.
- Report out

Everything depends on what else is in the pipeline, how complex your experiment is, how complex everyone else's experiment is, and resource availability. And, we haven't run the first experiment yet, so there's a lot of unknowns.

# What are the next steps?

- Get the Announcement of Opportunity
- Get documentation from the CoNNeCT Project
- Write your proposal
- Do your experiment

# ISS Announcement of Opportunity

- "Opportunity for the Use of the International Space Station by Domestic Entities other than U.S. Federal Government Agencies": NNH09CAO003O
  - http://www.nasa.gov/mission_pages/station/research/nlab/
  - CoNNeCT Experiments are an addendum to the master ISS AO
- Proposals solicited continuously, reviewed quarterly by Experiment Board to build an experiment program
  - Feedback from board may be useful
  - Pool of experiments is periodically reviewed
- Experiments selected based on variety of factors (more in next slides):
  - Relevance
  - Intrinsic Technical Merit
  - Programmatic Elements
- Also, there are opportunities through NASA SBIR program
  - Same evaluation factors regardless of source

# Evaluation Criteria - Relevance

- CoNNeCT Project Objectives
  - Broad participation (NASA, commercial, academia, etc.)
  - Reconfigurable and SDR technology advances
  - Demonstration of new or advanced future mission capability
- NASA Strategic Plan (NPD 1001.0)
  - Demonstration of Mission Applicability of SDR
  - Aspects of Reconfiguration (efficient use of processor, interprocess communication)
  - Spectrum Efficient Technologies
  - Space Internetworking (DTN)
  - Cognitive Applications
  - Position, Navigation and Timing (PNT)
  - Technologies/Waveforms for Formation Flying
  - High Data Rate Communications
  - Multi-access Communication
  - RF Sensing Applications
  - Uplink Antenna Arraying

# Evaluation Criteria – Tech Merit

- Technical Advancement
  - Has it been done before?
- On-Orbit Uniqueness
  - How do you use CoNNeCT's unique capabilities?
- Technical Approach
  - Does the work plan look reasonable?
- Technology Infusion
  - What do you plan to do with the results? How will NASA and the U.S. benefit?
- Experiment PI and Team Experience
  - Are you able to do the job?

# Evaluation Criteria – Programmatic

- Availability of Information – Publication
  - Full public disclosure (subject to export controls)
- Schedule
  - Does it fit in the experiment program?
- Participation and Coordination
- Use of Resources
  - Does it fit with other demands on resources?